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Original Communication

Cardiac injuries in car occupants in fatal motor vehicle collisions – An autopsy-based study

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ABSTRACT

Motor vehicle accidents contribute widely to population morbidity and mortality around the world, and cardiac injuries are a major factor determining outcome. Autopsy reports from 380 motor vehicle occupants who died in motor vehicle crashes in Adelaide, Australia, and Hamburg, Germany, over a 6-year period were reviewed, analysing the presence and type of cardiac injuries and their correlation with factors such as crash type, presence of seatbelt/airbag and vehicle speed as well as with the presence of other injuries which might predict the presence of cardiac injuries in a clinical setting. 21.1% had cardiac injuries identified macroscopically autopsy or histology. Cardiac injuries were the only cause of death or contributed to a fatal outcome in 76% of these cases. Sternal fractures and left-sided serial rib fractures were predictive of cardiac injury.

1. Introduction

More than a million people are killed in road accidents every year, making injuries sustained in motor vehicle collisions one of the leading causes of death worldwide.[24,29] Blunt cardiac injuries are a major factor influencing the prognosis of motor vehicle crash victims, and the presence and nature of cardiac injuries thus has major therapeutic implications. The diagnosis and therapy of blunt cardiac trauma has been addressed in clinical studies, but the management of blunt cardiac trauma patients is somewhat controversial, especially as the diagnosis of "minor", but still potentially fatal, cardiac trauma remains difficult.[10,15,19] An earlier autopsy study suggested that in unrestrained drivers, the presence of 8 or more rib fractures predicts cardiac and thoracic aortic injuries in frontal collisions.[11]

In order to assess the frequency and pattern, and to identify predictive factors of cardiac injuries in motor vehicle occupants, we reviewed the autopsy reports of 380 such fatalities subjected to medico-legal autopsy in Adelaide, Australia, and Hamburg, Germany, between 2000 and 2005.

2. Methods

We retrospectively analysed the reports of 380 motor vehicle occupant fatalities resulting from vehicle crashes where the victims were subjected to medico-legal autopsy in Adelaide, Australia, and Hamburg, Germany, from 2000 to 2005. The cases were identified by an electronic database search using the words "crash", "accident", "motor vehicle", "car", "driver" and "passenger". Victims who were involved in crashes resulting from an underlying organic disease, such as a myocardial infarction, were excluded from the study. The presence and type of cardiac injuries was assessed in each case, as well as major accompanying injuries, the cause of death and the survival time. Furthermore, the results of toxicological analyses were evaluated. Clinical records were included in the analyses when available. In addition to the autopsy data, the

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type of collision, the presence of seat belts and airbags, the position of the victim in the car and the vehicle speed at the time of the collision were obtained from police reports. Similar data were analysed from 300 control cases without cardiac injuries from Hamburg, Germany. Police data were analysed separately for the cardiac injury group and the control group without cardiac injuries. Statistical analysis was performed using Fisher's exact test.

3. Results

3.1. Study population

Of the 380 motor vehicle occupant fatalities included in the study, 80 (21.1%) cases presented with cardiac injuries. The mean age of all victims was 41.5 years (41.2 years in the cardiac injury group) with an age range of 19 months to 86 years. 77.9% of the cases were males. The mean age was similar in males (40.8 years, age range 19 months to 81 years) and females (42.2 years, age range 14–86 years).

3.2. Police data

Frontal (37 cases) and lateral (33 cases) collisions accounted for the majority of cases in the cardiac injury group. Six roll-over accidents and 4 others were identified. No significant differences in the distribution of collision types were identified between the cardiac injury group and the control group without cardiac injuries.

The mean speed at the time of the collision was 97.6 km/h (speed range 50–200 km/h) in the cardiac injury group and 95.8 km/h in the control group (range 50–200 km/h).

Seatbelts were worn in 58.8% of the cardiac injury cases and in 62.8% of the control cases. This difference was not statistically significant. In 8.8% of cardiac injury and 7.2% of control cases, it was unknown whether a seatbelt had been worn.

Airbags had opened in 46.3% of cases in the cardiac injury group and in 47.6% of cases in the control group. Again, there were no statistically significant differences between the two groups. In 30% of cases, it was unknown whether an airbag had opened.

3.3. Cardiac and other relevant injuries

Cardiac injuries were found in a total of 80 cases (21.1%). The injuries involved the pericardium in 41 cases (51.3%), all of which were lacerations, the right ventricle in 40 cases (50%), with lacerations comprising the majority of cases, the left ventricle in 27 cases (33.8%), with lacerations and contusions being the most frequent forms of injury, the right atrium in 24 cases (30%) and the left atrium in 12 cases (15%), all of which were lacerations, and the ventricular septum in 10 cases (12.5%), the injuries being either lacerations or contusions. The cardiac valves were lacerated in 8 cases (10%; aortic valve in 6 cases, pulmonary and mitral valve in 1 case each). Lacerations of the coronary arteries were found in 3 cases (Fig. 1).

Pericardial tamponade due to lacerations of cardiac chambers or coronary arteries was present in 7 cases (8.8%). In 32 cases (40%), multiple cardiac injuries were found.

Other major injuries involved the lungs in 55 cases (68.8%), the head in 16 cases (20%) and the abdominal organs in 10 cases (12.5%). 74 victims had bone fractures (92.5%). 7 victims had pelvic fractures, and 2 had fractures of the vertebral column.

Serial rib fractures were present in 71 cases (88.8%) from the cardiac injury group and in 234 cases (78%) from the control group.

Interestingly, in frontal crashes, left-sided serial rib fractures were found in 81.8% of the belted and 76.9% of the unbelted individuals from the cardiac injury group, but in only 26.8% of the belted and 15.8% of the unbelted individuals from the control group. Likewise, in lateral collisions, left-sided serial rib fractures were present in 84.2% of belted and 83.3% of unbelted individuals in the cardiac injury group and in no more than 21.4% of belted and 4.2% of unbelted individuals in the control group. These findings were statistically significant ($p < 0.00001$), indicating that the presence of left-sided serial rib fractures predicts cardiac injuries in belted as well as unbelted vehicle occupants involved in frontal and lateral collisions.

In contrast, right-sided rib fractures were almost equally distributed between the study groups in restrained and unrestrained individuals (frontal collisions: 45.5% belted and 38.5% unbelted victims in the cardiac injury group, 41.5% belted and 42.1% unbelted individuals in the control group; lateral collisions: 63.2% belted and 58.3% unbelted individuals in the cardiac injury group, 53.6% belted and 41.7% unbelted individuals in the control group).

Sternal fractures were present in 50% of belted individuals in the cardiac injury group and in 43.9% of belted individuals in the control group in frontal crashes. In contrast, 76.9% of unbelted victims from the cardiac injury group and only 10.5% of unbelted victims from the control group had sternal fractures. This was statistically significant ($p < 0.0002$), indicating a predictive usefulness of sternal fractures for cardiac injury in unbelted but not belted individuals involved in frontal motor vehicle collisions. In contrast, in lateral collisions, sternal fractures were almost equally distributed among the groups (31.6% of belted and 41.7% of unbelted individuals in the cardiac injury group, 32.1% of belted and 33.3% of unbelted individuals in the control group) (Fig. 2).

A significant correlation between the presence and type of injuries and the position in the vehicle or the speed of the car could not be established due to the small case numbers for each combination.

3.4. Cause of death, survival time

The cause of death was cardiac injury alone in 30 cases (37.5%) and polytrauma with cardiac injuries contributing to fatal outcome in 31 cases (38.8%). The remaining causes of death were head injury in 10 cases, multiple injuries with no major role of cardiac injuries in 6 cases and fat embolism in 3 cases. Survival times ranged from a few seconds up to several hours. The longest survival time was 24 h in a frontal collision case where the victim died of fat embolism. Expectedly, survival times correlated well with the overall injury severity. In the cardiac injury group, 13 patients (16.25%) survived for several hours and died in hospital. In 5 of these patients, cardiac injury was not diagnosed and was later found to be the cause of death.

3.5. Toxicology

30 victims had blood alcohol levels over the legal driving limit of 0.5‰ (0.05%), 6 of whom had concentrations of more than 1‰ (0.1%). In 17 cases (21.3%), illicit drugs were detected in blood samples. Interestingly, only 3 of these cases were from Hamburg.

4. Discussion

The present autopsy-based study of cardiac injuries in motor vehicle occupants following collisions demonstrates that blunt cardiac injury is a frequent event.

It has been shown repeatedly and is now generally accepted that the proper use of seat belts reduces the risk of thoracic injury in motor vehicle collisions, and airbags have also been demonstrated to lower the risk of thoracic injuries.[5,7,13,16,20] Others, however, have found that in restrained drivers, the risk of thoracic injury may even increase if an airbag opens.[18] As well, seat belts themselves may be responsible for significant injuries in high speed crashes,[2,12] and in

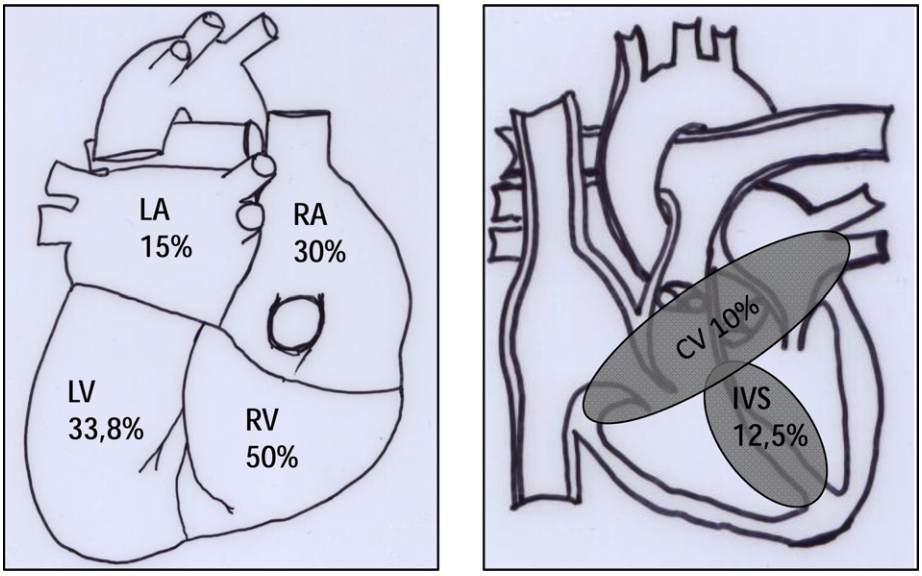

Fig. 1. Distribution of cardiac injuries in frontal and lateral crashes. CV = cardiac valves, IVS = interventricular septum, LA = left atrium, LV = left ventricle, RA = right atrium, RV = right ventricle.

particular children may be vulnerable if seat belts are not fitted correctly.[3,25] Strikingly, we did not observe a significant difference in the use of safety belts and airbags between the cardiac injury group and the control group. However, we only analysed severe crashes with fatal injuries, and thus those individuals who survived because they did not sustain severe cardiac injuries due to proper safety belt use are not included in our investigation. Thus, our results do not contradict the protective effect of restraining devices. They do, however, indicate that, even if a safety belt was worn, severe blunt cardiac trauma must always be considered in patients presenting after motor vehicle collisions.

Surprisingly, we found that in our series of fatal motor vehicle collisions, cardiac injuries were not more frequent in frontal collisions than in other collision types. It has been shown that frontal collisions, as opposed to other collision types, predispose to thoracic aortic injuries,[30,31] but reliable data on collision types predisposing to blunt cardiac trauma are missing in the recent literature. Our data suggest that at least in fatal collisions, the type of collision is of minor relevance concerning the sustaining, and type, of cardiac injury.

Regarding the cardiac injury pattern, it was striking that the cardiac ventricles were more often affected than the atria, although they have thicker walls and have been shown to be less frequently

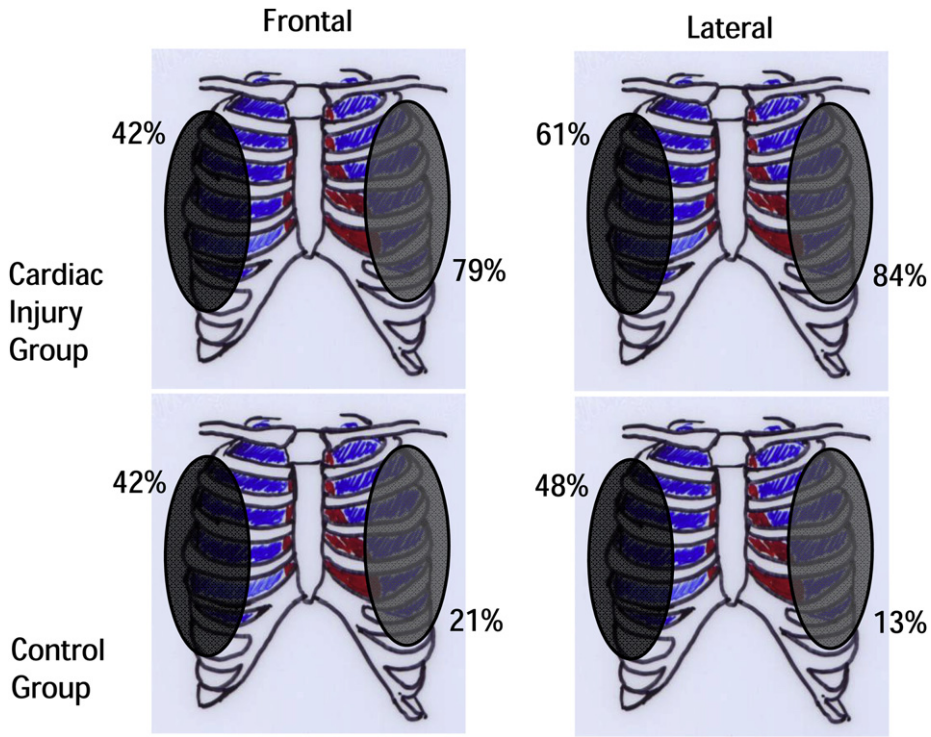

Fig. 2. Frequency of left- and right-sided serial rib fractures in frontal and lateral collisions in the cardiac injury group vs. the control group. Percentages are shown as mean between belted and unbelted individuals.

affected in other types of blunt trauma such as falls from a height.[32] This may be due to the fact that anatomically, the ventricles are more exposed to the chest wall, which is compressed in the course of a motor vehicle collision. The majority of injuries found in the present study consisted of lacerations, followed by contusions.

Our results suggest that in frontal collisions, the presence of left-sided serial rib fractures predicts the presence of cardiac injuries in belted and unbelted individuals irrespective of the type of crash, whereas the presence of right-sided rib fractures was not predictive of cardiac injury. Sternal fractures were predictive of cardiac injuries in belted but not unbelted individuals, as has been suggested previously.[11]

Cardiac injuries were found to be the cause of death or a major contributing factor for fatal outcome in more than 70% of the cases when present. 13 patients survived the accident for several hours and were treated in hospital. 5 of these patients were not diagnosed with cardiac injury, which later caused death. The injuries in these cases were cardiac contusion in 3 cases, pericardial tamponade due to atrial laceration in 2 cases and pericardial tamponade due to coronary artery laceration in 1 case. All these injuries might have been amenable to successful surgical intervention, had they been diagnosed in time. These findings again underline the importance of a thorough cardiological investigation of patients who present after motor vehicle collisions. Cardiac contusion may be present even in the absence of other blunt chest injuries.[22] It can be diagnosed employing a combination of electrocardiography, echocardiography and cardiac troponin measurements, as each of the methods alone may be non-specific.[4,9,23,28,33] The type of treatment depends on the severity of contusion and can range from conservative management to emergency surgical intervention.[27] It has been recently suggested that the separation of blunt impact without demonstrable injury to the heart, so-called “commotio cordis”, from those cases where there is bruising or associated injury is a somewhat artificial classification, as cases are in practice all part of an overlapping spectrum of merging injuries.[17] The diagnosis of coronary artery rupture can be made by Doppler echocardiography,[21] and pericardial tamponade and cardiac lacerations can be diagnosed by transthoracic or transoesophageal echocardiography. In severe blunt chest trauma, emergency thoracotomy permits rapid diagnosis and immediate surgical repair of cardiac injuries and has been shown to improve the prognosis even in patients with massive cardiac injuries.[1,8,14]

In conclusion, we suggest that a thorough cardiological examination, including electrocardiography, echocardiography and troponin testing, should be performed in all patients presenting after motor vehicle collisions with possible blunt chest trauma, and that cardiac injuries should be suspected especially in patients with left-sided serial rib fractures and sternal fractures. If severe chest trauma has been sustained, emergency thoracotomy with cardiopulmonary bypass can improve the prognosis even in patients without cardiac injury[6] and should always be considered. Consequently, patients with blunt chest trauma after motor vehicle collisions should, wherever possible, be admitted to a specialised unit with cardiopulmonary bypass capabilities.

4.1. Limitations of the study

Due to the retrospective nature of the present study, measurements of crash severity, such as Δv, maximum vehicle crush and intrusion, were not available in most cases. Thus, the injury pattern could only be related to the speed at the time of the incident, which we recognize is not the best parameter of crash severity. Correlations between speed and cardiac injury patterns were not found. However, a correlation between crash severity and cardiac injuries has been demonstrated previously.[7,26]

4.2. Conclusions

Cardiac injuries contribute widely to patient morbidity and mortality after motor vehicle crashes. An early diagnosis and adequate therapy can prevent life-threatening consequences in patients with such injuries. Sternal fractures and left-sided serial rib fractures are predictive of cardiac injury in motor vehicle occupants after road traffic accidents.

Conflicts of interest

The authors declare that there are no conflicts of interest with regard to this publication.

References

1. Brathwaite CE, Rodriguez A, Turney SZ, Dunham CM, Cowley R. Blunt traumatic cardiac rupture: a 5-year experience. *Ann Surg* 1990;**212**:701–4.
2. Byard RW. Shoulder–lap seatbelts and thoracic transaction. *J Clin Forensic Med* 2002;**9**:92–5.
3. Byard RW, Noblet H. Child booster car seats and lethal seat belt injury. *J Paediatr Child Health* 2004;**40**:639–41.
4. Cachecho R, Grindlinger GA, Lee VW. The clinical significance of myocardial contusion. *J Trauma* 1992;**33**:68–71.
5. Campbell BJ. Safety belt injury reduction related to crash severity and front seat position. *J Trauma* 1987;**27**:733–9.
6. Chughtai TS, Gilardino MS, Fleiszer DM, Evans DC, Brown RA, Mulder DS. An expanding role for cardiopulmonary bypass in trauma. *Can J Surg* 2002;**45**:95–103.
7. Conroy C, Hoyt DB, Eastman B, Holbrook TL, Pacyna S, Erwin S, et al. Motor vehicle-related cardiac and aortic injuries differ from other thoracic injuries. *J Trauma* 2007;**62**:1462–7.
8. Duda AM, Ilada PB, Molnar RG, Bachulis BL. Successful repair of blunt cardiac rupture involving both ventricles. *Cardiovasc Surg* 1999;**7**:263–5.
9. Ferjani M, Droc G, Dreux S, Arthaud M, Goarin JP, Riou B, et al. Circulating cardiac troponin T in myocardial contusion. *Chest* 1997;**111**:427–33.
10. Galan G, Penalver JC, Paris F, Caffarena Jr JM, Blasco E, Borro JM, et al. Blunt chest injuries in 1969 patients. *Eur J Cardiothoracic Surg* 1992;**6**:284–7.
11. Hitosugi M, Ishihara T, Takatsu A, Shigeta A. Prediction of injuries to the heart and thoracic aorta in unrestrained drivers. *Leg Med* 2002;**4**:103–8.
12. James RA, Byard RW. Asphyxiation from shoulder seat belts. An unusual motor vehicle injury. *Am J Forensic Med Pathol* 2001;**22**:193–5.
13. Kahane C. *Fatality reduction by airbags: analyses of accident data through early 1996*. Washington, DC: National Highway Traffic Safety Administration; 1996.
14. Kavoulis J, Golocovsky M, Champion HR. Predictors of outcome in patients who have sustained trauma and who undergo emergency thoracotomy. *Arch Surg* 1993;**128**:1158–62.
15. Koehler SA, Shakir A, Ladham S, Rozin L, Omalu B, Dominick J, et al. Cardiac concussion: definition, differential diagnosis, and cases presentation and the legal ramification of a misdiagnosis. *Am J Forensic Med Pathol* 2004;**25**:205–8.
16. Loo GT, Siegel JH, Dischinger PC, Rixen D, Burgess AR, Addis MD, et al. Airbag protection versus compartment intrusion effect determines the pattern of injuries in multiple trauma motor vehicle crashes. *J Trauma* 1996;**41**:935–51.
17. Marshall D, Gilbert J, Byard RW. The spectrum of findings in cases of sudden death due to blunt cardiac trauma – ‘commotio cordis’. *Am J Forensic Med Pathol* 2008;**29**:1–4.
18. Matthes G, Schmucker U, Lignitz E, Huth M, Ekkernkamp A, Seifert J. Does the frontal airbag avoid thoracic injury? *Arch Orthop Trauma Surg* 2006;**126**:541–4.
19. McGillycuddy D, Rosen P. Diagnostic dilemmas and current controversies in blunt chest trauma. *Emerg Med Clin North Am* 2007;**25**:695–711. viii–ix.
20. McGwin Jr G, Metzger J, Alonso JE, Rue 3rd LW. The association between occupant restraint systems and risk of injury in frontal motor vehicle collisions. *J Trauma* 2003;**54**:1182–7.
21. Meluzin J, Groch L, Toman J, Hornacek I, Fischerova B. Rupture of the coronary artery after blunt nonpenetrating chest wall trauma detected by color Doppler echocardiography: a case report. *J Am Soc Echocardiogr* 2000;**13**:1043–6.
22. Michalodimitrakis EN, Tsatsakis AM. Vehicular accidents and cardiac concussion: a traumatic connection. *Am J Forensic Med Pathol* 1997;**18**:282–4.
23. Moulin A, Bason-Mitchell M, Henderson SO. Cardiac contusion diagnosed by cardiac troponin. *Am J Emerg Med* 2002;**20**:382–3.
24. Peden M, Scurfield R, Sleet D, Mohan D, Jyder A, Jarawan E, et al. *World report on road traffic injury prevention*. Geneva: World Health Organization; 2004.
25. Riches KJ, James RA, Gilbert JD, Byard RW. Fatal childhood vascular injuries associated with seat belt usage. *Am J Forensic Med Pathol* 2002;**23**:45–7.
26. Richter M, Krettek C, Otte D, Wiese B, Stalp M, Ernst S, et al. Correlation between crash severity, injury severity, and clinical course in car occupants with thoracic trauma: a technical and medical study. *J Trauma* 2001;**50**:10–6.
27. RuDusky BM. Classification of myocardial contusion and blunt cardiac trauma. *Angiology* 2007;**58**:610–3.
28. Salim A, Velmahos GC, Jindal A, Chan L, Vassiliu P, Belzberg H, et al. Clinically significant blunt cardiac trauma: role of serum troponin levels combined with electrocardiographic findings. *J Trauma* 2001;**50**:237–43.

29. Sethi D, Racioppi F, Bertollini R. Preventing the leading cause of death in young people in Europe. *J Epidemiol Community Health* 2007;**61**: 842–3.
30. Sevitt S. The mechanisms of traumatic aortic rupture of the thoracic aorta. *Br J Surg* 1977;**64**:166–73.
31. Siegel JH, Smith JA, Siddiqi SQ. Change in velocity and energy dissipation on impact in motor vehicle crashes as a function of the direction of crash: key factors in the production of thoracic aortic injuries, their pattern of associated injuries and patient survival. A Crash Injury Research Engineering Network (CIREN) study. *J Trauma* 2004;**57**:760–77.
32. Turk EE, Tsokos M. Blunt cardiac trauma caused by fatal falls from height: an autopsy-based assessment of the injury pattern. *J Trauma* 2004;**57**:301–4.
33. Vignon P, Boncoeur MP, Francois B, Rambaud G, Maubon A, Gastinne H. Comparison of multiplane transesophageal echocardiography and contrast-enhanced helical CT in the diagnosis of blunt traumatic cardiovascular injuries. *Anesthesiology* 2001;**94**:615–22.